ISSUES AND CHALLENGES OF FEDERATING BETWEEN DIFFERENT TRANSPORTATION SIMULATORS

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ISSUES AND CHALLENGES OF FEDERATING BETWEEN DIFFERENT TRANSPORTATION SIMULATORS

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Dedicated to the memory of my father, William Puglisi.

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Summary

As the container traffic at the Port of Savannah is expected to increase, its impacts need to be evaluated to address major concerns regarding the roadway network surrounding the port and the overall operations of the port. A federation of two disparate simulators was created in order to model the impacts of increased container traffic.

The Port of Savannah was modeled using Rockwell Arena© and the surrounding roadway network was modeled using PTV VISSIM©. These two simulators operated concurrently and continually provided feedback with one another. The challenges that arose from this combination were largely due to the time structure of the models. Arena© is a discrete event simulator and VISSIM© is a continuous traffic simulator.

A basic model, where these two pieces of software could pass information between one another, was initially created as a test bed for methods required to federate the two models. These basic concepts were then applied to a comprehensive model of the Port of Savannah and the surrounding area.

This federated modeling approach for the Port of Savannah allowed the analysis to reflect the interaction of behaviors unique to the port and local roadway network. For instance, the federated model successfully captured how delays at the Port of Savannah increased as a result of increased congestion in the surrounding roadway network.

It is anticipated that this prototypal model will be a base for future research into the area of federating disparate transportation simulators, as well as aid in the further exploration of a transportation run-time interface.

CHAPTER 1

INTRODUCTION

As the Port of Savannah continues to see an increase of container traffic, it is important to analyze the effects this will have on port operations and the surrounding roadway networks. Increasing container volume through the port may lead to increased truck traffic and congestion in and around the port. Likewise, increasing congestion around the port will lead to delays in moving trucks to and from the port. In this research effort, a port model is federated with a traffic network simulation to provide a platform to analyze this interaction.

1.1 Motivation Statement

Trucks are a critical resource at most seaports because they are the sole transporters of containers between local origins and local destinations. For example, after off-loading at the port of Savannah, many containers are shipped to a local rail cargo yard or to a local distribution center by truck. As most of these trips are local, many trucks make multiple round trips per day. As off-port traffic congestion increases, the number of round trips a truck can complete per day decreases. This may become problematic as only a finite number of trucks are available for transport. Decreasing the daily productivity of the trucks can result in direct increases in the delay experienced by containers waiting to be transported. Since trucks are the limiting factor in the overall operations of the port, any model of port operations should be able to track trucks both in the port and in the surrounding roadway network.

1.2 Model Overview

This analysis is undertaken using a federated simulation of two different computer models derived from two separate computer modeling software packages. The port operations are modeled using Rockwell Arena© and the surrounding roadway network is modeled using PTV VISSIM©. Additional features, such as local distribution centers and a local rail terminal are included in the Arena model.

1.2.1 Simulation Model Platforms

Arena© is a discrete, event based simulation that utilizes the SIMAN simulation programming language. Arena's intended use is primarily for analyzing supply chains, manufacturing, processes, logistics, distribution centers, and warehousing. Arena© maintains a calendar of future events and uses a logical clock to advance the simulation time. Once events are complete at the current time, the logical clock advances to the time of the next logical process in the event list, disregarding the time between two events [1-4]. VISSIM© is a microscopic continuous simulation used to analyze traffic and transit operations. As a continuous model, it institutes a time-step advancement to progress its simulation time [5].

1.2.2 Modeling Approach

To model the interaction effect of the port and traffic network, a federated model is needed as the activities of these two facilities are intertwined, each dependent on continuous feedback from the other. A federation is a global conceptual model (GCM) consisting of multiple simulations, or federates, and maps the exchange of data between them. To federate two disparate simulators, a runtime infrastructure (RTI) interface is needed to maintain interconnection during the federated simulation experiments [6].

One critical aspect of a RTI in this analysis is the synchronization of information between federates. The timestamp of the information passed from one federate must not be earlier than the simulation time of the receiving federate. If a piece of information is sent to a model where the timestamp is earlier than the current simulation time, this information would be rendered useless as neither model currently has a rollback ability. Therefore a conservative synchronization approach is implemented for this project, with the federation maintaining its own logical clock (LC) in order to sync the two federates. That is, if each model is defined as a logical process, LP_i and LP_j respectively, with an associated LC_i and LC_j, a conservative simulation is defined as LP_j never receiving a message from LP_i such that the message timestamp is earlier than LC_j [1].

To implement the conservative synchronization, the RTI runs one federate (e.g. the VISSIM© traffic simulation) for a period of time, Δt, until time, t_1, and then runs the second federate (e.g. the Arena© port model) for the same Δt, again until t_1. This process continues, forwarding each model in equal increments of Δt until some predefined stop condition is reached, such as time t_n. After each increment of Δt, information is passed from one model to the other.

There are several pieces of information being passed back and forth between the models. The primary information passed allows for a modeling of trucks and container movements between the models. Container and truck information passed includes unique identification numbers, timestamps for particular occurrences within the model, and origin and destination identifiers. This information allows for a tracking of every entity within the model at all times and therefore is the foundation for the presented results. In Arena©, entities are used to carry the listed information. In VISSIM©, every vehicle is assigned unique identifiers that ties back to a record of container and truck information maintained in a Microsoft Excel© spreadsheet.

The federation of these models allows for measuring the total time containers spent at each location (simulated in the Arena© model), and travel times and intersection queue lengths on the local roadway network (simulated in the VISSIM© model). As he federation tracks each individual entity, the delay experienced by individual entities can also be measured. This information may then be used to determine if the port and the surrounding infrastructure will be able to handle the increase in container volume being processed by the Port of Savannah. The results should show exactly where any bottlenecks or capacity constraints are located and provide guidance for resource allocation for upgrades.

1.3 Background & Literature Review

Recently, research has been dedicated towards shifting simulations from single monolithic models to distributed architectures. A standard, called High Level Architecture (HLA) was initially developed for use by the U.S. Military to interface multiple simulations. The premise of HLA is based on the notion that no single simulation can satisfy all uses and users [7]. Klein et al (1998) suggests that HLA seems to be very well suited for civilian application. Coupling distributed systems or simulations is something of interest for traffic management applications [8]. According to Daiheng Ni (2006), the "new generation of transportation simulators is envisioned to be multiscale in resolution, parallel in execution, and driven by objects" [9]. As the research suggests, integrating HLA with traffic simulation may result in many benefits to the industry.

HLA is defined by three components: the interface specification, the object model, and the HLA rules. The interface specification requires the RTI to perform six services: federation management, declaration management, object management, ownership management, time management, and data distribution management. The HLA object models are a set of shareable elements of the federation. The HLA defines two types of object models, which are the Federation Object Model (FOM) and the simulation object model (SOM). The FOM describes the set of objects, attributes, and interactions which are shared across a federation. The SOM describes the simulation in terms of the types of objects, attributes, and interactions it can offer to future federations. The HLA rules are further subcategorized into "federate" and "federation" rules. The key principles are that during runtime, all object representations take place within the federates themselves and not the RTI. All information must be passed with the RTI using the interface specification [7].

With a basic understanding of what HLA is, the principles can be applied to the new generation of transportation simulation. This new generation can include multiple simulation processes that can communicate and synchronize with each other in a way such that each process is a part of a larger transportation network. This could be done in two ways, either being parallel on the same computer processor or distributed over multiple processors. For the purposes of this project, a spatially parallel simulation of VISSIM© and Arena© on a single computer is created. This means that the large network is divided spatially into several small sub-networks connected with an RTI [9].

The idea that no single simulation can satisfy all uses and users is epitomized by this project. A discrete logistics simulator is necessary to effectively model the Port of Savannah and a continuous traffic simulator is necessary to effectively model the surrounding roadway traffic. The principles of HLA allow for the interoperability of these two simulators instead of creating an entirely new simulation environment for this single purpose. This in turn reduces the time and effort required to create a single purpose model [7].

How HLA will impact the field of traffic engineering, is that it will add a degree of interoperability, flexibility and reusability. Modular simulation models are easier to develop, test and maintain than the traditional monolithic models. They also allow for the models to be easily adapted and extended in future uses [8]. As this project grows in complexity, it will take on more "modules." The proof of concept discussed in this report, is the first and primary version of an integrated model of the Port of Savannah, incorporating a collection of roadway network and port components that will induce an effect on the overall operations of the model.

To illustrate the distinction in the different approaches to transportation simulation, common terms must be defined. The difference between a monolithic model and a distributed or parallel model is that a monolithic model contains all relevant information in one single model. A distributed or parallel model is divided into several sub-models, each containing a part of the entire system being modeled. The difference between static and dynamic elements is that static elements are not altered during the simulation model execution. Dynamic elements have the option of altering their attributes or properties during the simulation model execution. Static information includes items such as street parameters and traffic characteristics, geometric layouts, port facilities, and intersection control (however, future versions may allow intersection control to become dynamic) [8]. Dynamic elements, in the case of this project, are primarily limited to traffic input (for example, the trucks themselves entering VISSIM© or Arena©). There are also two categories of information within the model: primary and secondary. Primary information is information the simulators utilize during runtime, such as simulation variables, and they are usually dynamic in nature. Secondary information is the information needed to support the simulation, such as input files or the model code itself [8].

For the purposes of this project, a completely HLA-compliant model is not constructed, but its principles are used. The objective of this initial effort is to show that two disparate simulators can be federated in a way that is beneficial to the transportation community. This will hopefully open the door to further research into creating a completely HLA-compliant transportation run-time infrastructure.

Some literature already suggests that research has previously been undertaken into utilizing HLA for the purposes of traffic simulation, but its use is sporadic and extremely focused. One such example is the research by Jenkins et al (2004) [10] for a passing behavior study. The research federated VISSIM and DriveSafety© [11], a driving simulator. The outcomes of this research, with regards to federating simulators in the field of traffic engineering, further support the notion that this practice extends the usefulness of each of the individual application.

CHAPTER 2

PROCEDURE

As a first step, the capabilities of Arena© and VISSIM© were analyzed to determine the reasonableness of federation. Both Arena© and VISSIM© have component object model (COM) interfaces using Visual Basic for Applications (VBA), and both have read/write capabilities [3], [12]-[13]. The COM interface in Microsoft Excel© will be used as the foundation for RTI, and the worksheets in the Excel© Workbook will be used to communicate information between the two federates.

As a first step in the federation development, basic models were created in both Arena© and VISSIM© to represent the more complex models of the Port of Savannah and the surrounding roadway network. Starting with a simplified prototype makes challenges more apparent and rectifying them much simpler. It also allows the validation process of the proof of concept to be more straight forward, eliminating the need to simultaneously debug errors in the individual federates. Once it can be validated that these two models are working together properly, the concept can then be applied to a more detailed system of models.

2.1 Developing a Conceptual Model

Arena© models entities through a process which is defined by a flowchart of blocks and modules. Entities are the pieces of data that are processed through the model. The entities are mapped through processes that are represented by blocks and/or modules. Blocks represent simple logical constructs in Arena© used to control entities. Blocks sometimes require elements as inputs to aid in defining the purpose and actions of the block. Elements are resources or characteristics used to describe the model components [2]. A module is a predefined logical construct of blocks and elements, which typically captures the more complex actions the modeler wants an entity to perform. All references to specific Arena© constructs, such as a *queue* block or *dispose* module, will be italicized in the subsequent text.

2.1.1 Vehicle Creation in Arena©

The first challenge of the project was developing a method to dynamically create an entity in Arena©. Since the preexisting modules in the program did not allow dynamic creation, new modules needed to be developed [13]. A *vehicle input* module was created using basic Arena© blocks that could interface with the RTI to create an entity in Arena© during simulation runtime. The module's logic is outlined in Figure 1 and the user interface is shown in Figure 2.

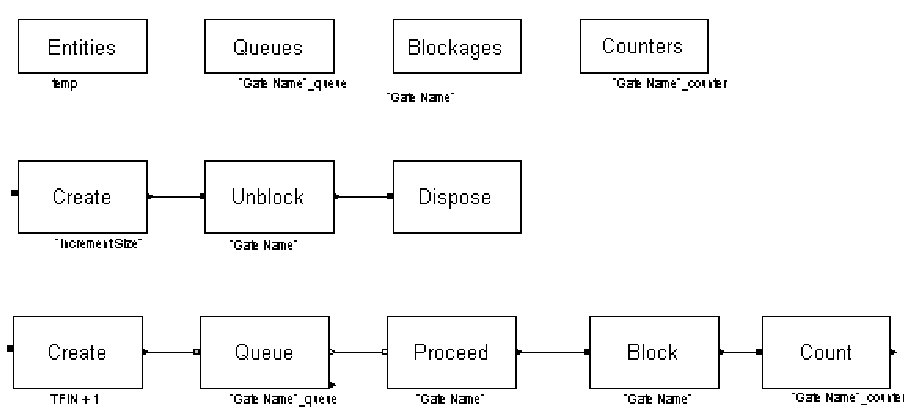

Figure 1: *Vehicle Input* Module Logic.

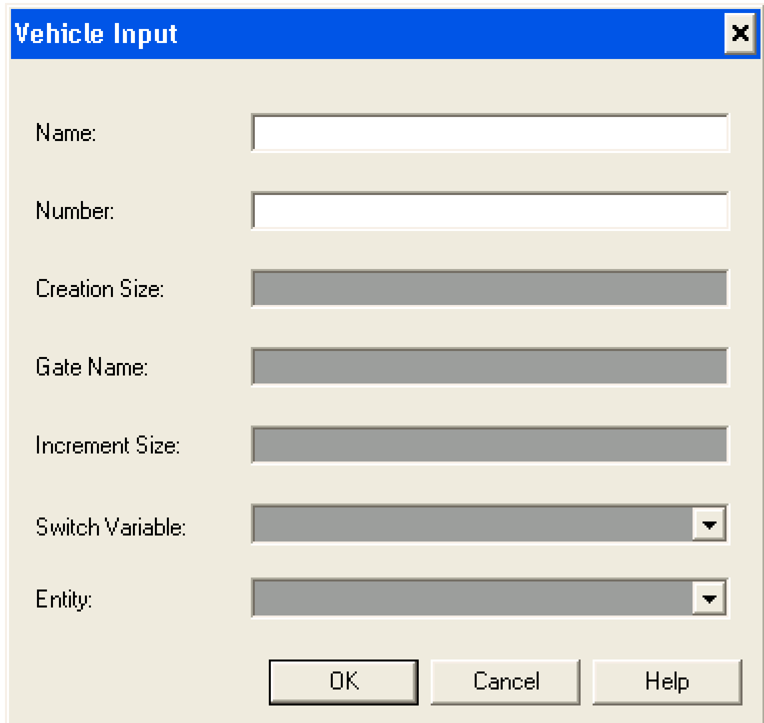

Figure 2: User Interface of the *Vehicle Input* Module.

The module creates an initial batch of entities at the simulation initialization to be utilized as a source of entering containers during simulation runtime. These entities are queued within the module until needed, which is indicated through an external variable value, referred to as a switch variable in Figure 2. A variable value of “0” indicates not to release an entity (i.e. a container does not enter the port during the current time step), and a value of “1” indicates to release an entity (i.e. a container does enter the port during the current time step). Variables in Arena can be dynamically altered using VBA COM. Thus, the switch variable is able to be altered by the RTI to indicate to Arena© to allow an entity to proceed from the queue, exit the module, and enter the main port model.

For example, changing the switch variable to a value of "1" causes the *unblock* block to change the number of blockages from 0 to 1, removing the blockage preventing the entities from proceeding. As the entity exits the module, it passes through a *block* block that reestablishes the number of blockages to 1 and prevents other entities from following it out of the module. Essentially, the *unblock* and *block* blocks serve to create a gating system that allows one container out of the waiting batch of containers and into the port. This logic is used to represent a container that is entering the port model from the roadway model. The logic to check the switch variable is executed every time step through the use of a logical entity (i.e. an entity that does not have a real-world physical equivalent). The logical entity controlling the *unblock* block does not produce any output statistics.

The user can input the initial "Creation Size" which should always be greater than the number of entities expected to be "created" from this module. This is because all entities must be created at model initialization and stored within the module for release at some later point. The user also inputs a "Gate Name" to be given to this module. This is used to name the internal queues and blockages so that multiple instances of this module have unique element names. The "Increment Size" is equal to the time steps that will be used throughout the federated system. This input will also appear in the module used to control the time advancement of the Arena simulation. The user also needs to input the "Switch Variable" that will be used to cue the module to release an entity. This requires the user to input a *variables* element into the model, and add a variable that will be used by the *vehicle input* module. The "Entity" field is used to create the same entities that are being used in the model.

The limitation of this module, however, is that it can only release one entity during one time interval. However, because it is a module, it can have multiple instances within the model, each uniquely defined. The time interval of the model can also be manipulated so that at most, only one vehicle could possibly transition between Arena© and VISSIM© at any given location.

2.1.2 VISSIM© and Arena© Synchronization

The second goal is to allow for the synchronization of Arena© and VISSIM©. In order for the RTI to properly pass information between the federates at the appropriate times, both models must be able to be paused at the same time steps. The VISSIM© simulation is constrained to proceed with increments of equal time length. Therefore, it is necessary to incorporate a clock feature in Arena that guarantees an event at the end of each VISSIM© time step, allowing for a pause of the model in sync with VISSIM©. A *continuous clock* module was created and is shown in Figure 3, and its user interface is shown in Figure 4.

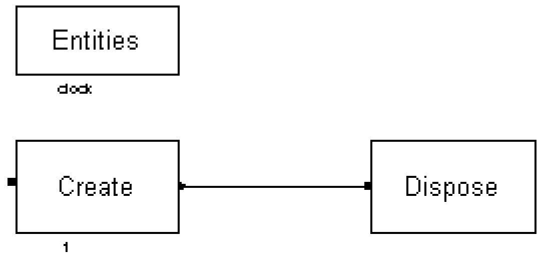

Figure 3: *Continuous Clock* Module Logic.

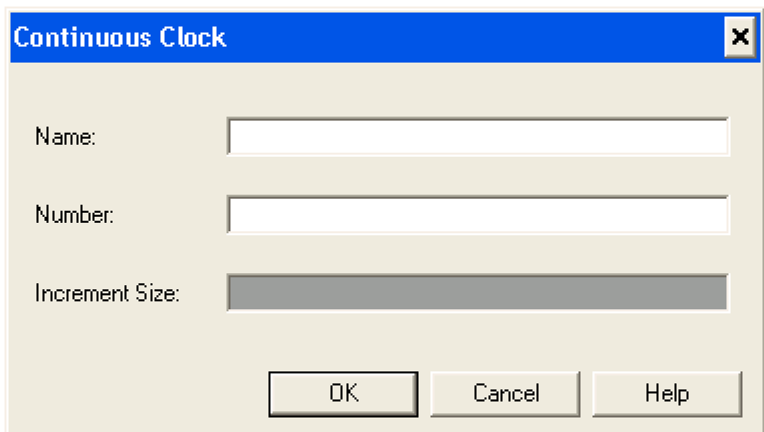

Figure 4: User Interface of the *Continuous Clock* Module.

The module's logic is straightforward. It creates an entity every time interval, where the time interval is user specified. This logic exploits Arena's© event-based simulation clock by creating an entity at a specified interval forcing the model's simulation clock to arrive at a time equal to that in VISSIM©.

2.1.3 Entity Tracking

The *read/write* module in Arena is used to pass attribute information back and forth to the RTI. When an entity leaves Arena, it will write its attributes to an Excel worksheet, and when that entity re-enters Arena it will read them back from Excel©.

For VISSIM©, simple COM commands are used to track vehicles. To locate vehicles exiting the network, the simulation is paused and the network is searched for vehicles about to exit the model. Additionally, there is a vehicle create command that can place vehicles in the network at any given coordinate. When a vehicle is created, its unique vehicle identification number (ID) is recorded into Excel to correspond with the entity information from Arena [12].

2.1.4 Federation Test

The preceding modules and principles are implemented for a very basic set of Arena© and VISSIM© models to test and validate the federation. An overview of how these models are mapped is shown in Figure 5, and the location names displayed over the terminals define which part of the Arena© model the trucks enter or exit. The Arena model consists of a simple representation of one port gate, two distribution centers, and access to a highway for long distance trucking. An example of the gate logic is seen in Figure 6. The VISSIM© model is a simple four-leg intersection, with each leg leading to one of the four representative locations in the Arena© model, as shown in Figure 7.

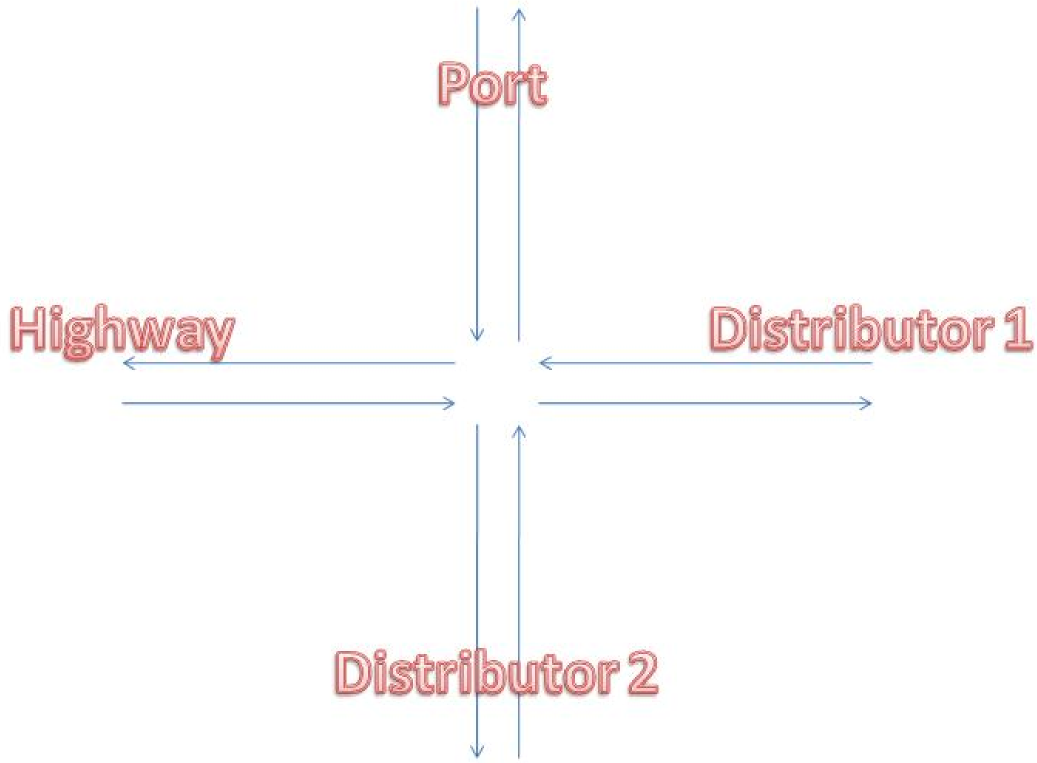

Figure 5: Overview of the VISSIM©-Arena© Federated System.

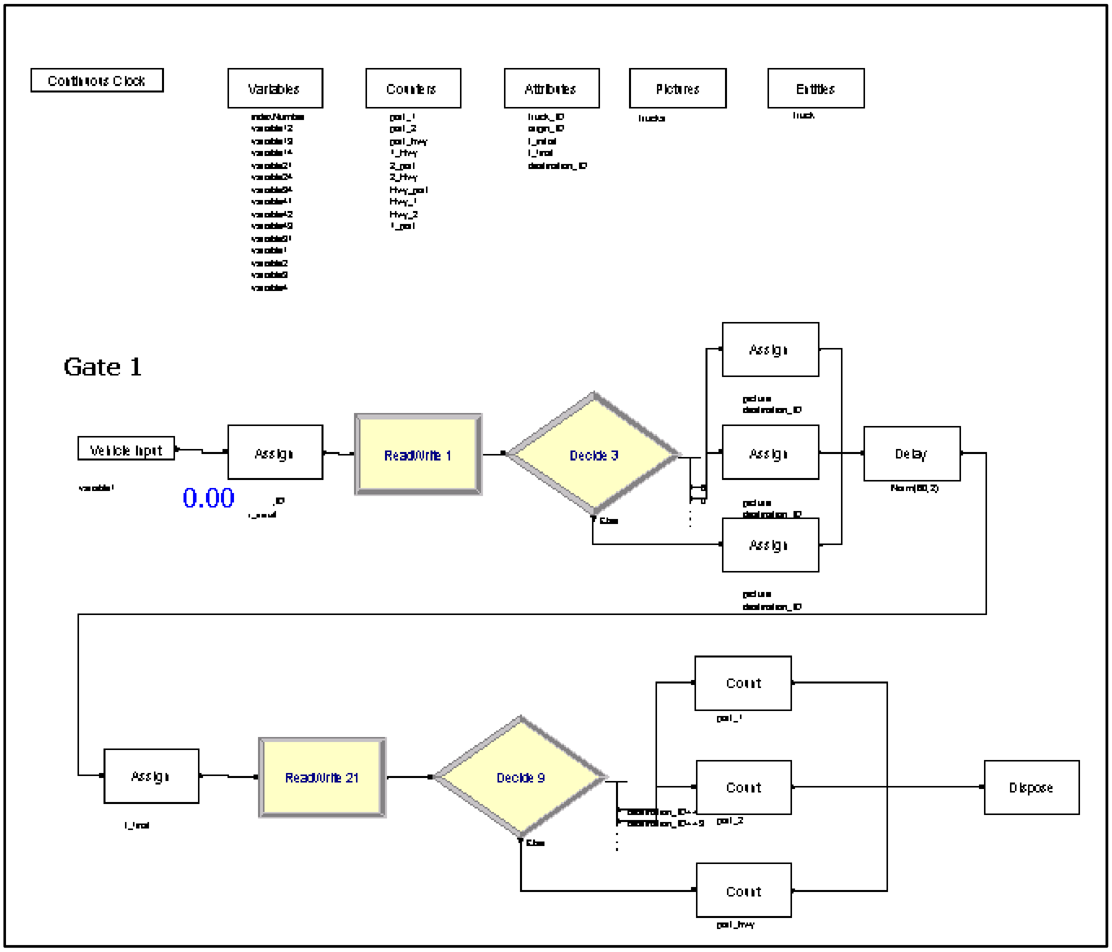

Figure 6: Representation of a Gate at the Port of Savannah in the Basic Arena© Model, as well as an Overview of the Elements Used.

The first module in the logic is the *vehicle input* module discussed previously. This is followed by an *assign* block which stamps the entity with the time it is released into the main Arena© model. The third block is a *read/write* module which reads entity-related information from Excel© that was written when the truck represented by this particular entity was last present in Arena©. The next block is a *decide* module which sets an entity's next destination based on user input percentages. The *delay* block is a simplistic representation of the time an entity is expected to spend inside the Port. The next *assign* block stamps the time the entity exits Arena. The following *read/write* module writes all of the updated entity's attributes into Excel©. This information is used by the RTI to transfer entities from the Arena© federate to the VISSIM© federate. Finally, the *decide* module sorts entities based on their destination ID and the *count* blocks maintain a running tally of trucks headed to each destination from this particular location. This information is used for validating the model. After the entities are counted, they are disposed upon entering the *dispose* block and are removed from the Arena© model. It is important to note that the only block or module in this Arena© port representation that has a time delay associated with it is the *delay* block.

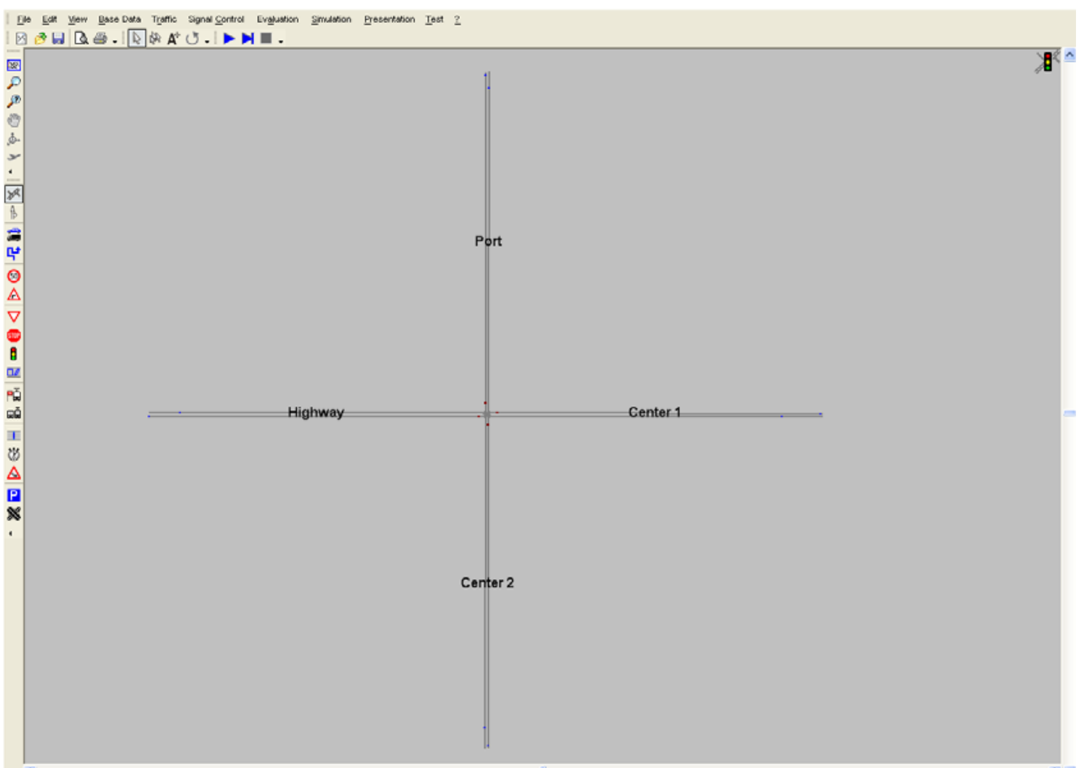

Figure 7: Overview of the basic VISSIM© model.

The VISSIM© model shown in Figure 7 is a basic intersection. Each approach is one-quarter mile long. Data collectors can be seen in Figure 7 at the terminals of the four approaches, and are illustrated in blue in the figure. The data collection points for links with vehicles entering the VISSIM© model are located at the beginning of each link. The federation logic assumes a vehicle within the last 25 meters of a link is about to exit the VISSIM© network. The data collection point is placed before this zone to guarantee that all vehicles are counted.

Routing decisions can also be seen in Figure 7 near the intersection and are red in color. The routing decisions are necessary to ensure vehicles travel to their appropriate destination. For this study, routing decisions are based on vehicle classes. There are four vehicle classes and four vehicle types in the model. When a vehicle is created in VISSIM© it is assigned a certain vehicle type, with each vehicle type associated with one of the possible destinations. Since the routing decisions are based on vehicle classes, each class is uniquely linked to its corresponding type. The dialog boxes for vehicle types and vehicle classes are shown in Figure 8 and the dialog box for routing decisions is shown in Figure 9.

As seen in Figure 8, all four vehicle types are heavy goods vehicles (HGV) and have a distinct location in their names. The vehicle classes also carry the destination in their name. It is important to note that the vehicle type number and vehicle class number are not the same number. As seen in the vehicle class dialog box, vehicle class 3 (To Port) can be defined to be only vehicles of vehicle type 1 (HVG – To Port). This means that whenever a vehicle is created of vehicle type 1 it will also be of class 3. Figure 9 shows the dialog box of the routing decisions and how routing decisions are made based on the vehicle class. For example, the highlighted route decision (number 3) in Figure 9, will send a vehicle of class 2 (To Dist 2) from link 3 (start link) to link 6 (destination link) which leads the vehicle to distributor 2 from wherever it is in the model.

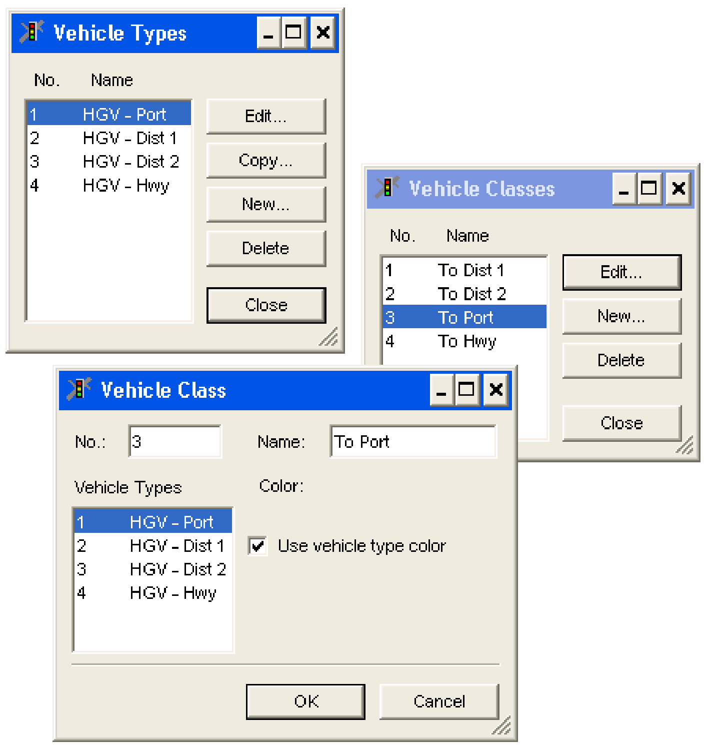

Figure 8: Vehicle Type and Vehicle Class dialog boxes in VISSIM©.

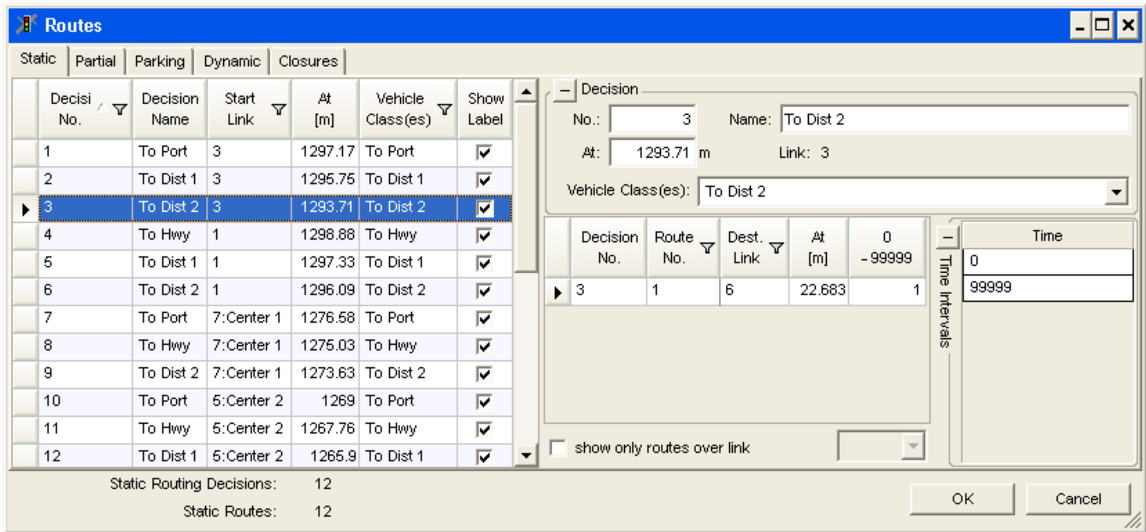

Figure 9: Routing Decisions Dialog box in VISSIM©.

```
For Each vehicle In vehicles2
      If vehicle.AttValue("LINKCOORD") > (length2 - 25) Then
            s.VariableArrayValue(1) = 1
            ID1 = vehicle.ID
            vissim.net.Vehicles.RemoveVehicle (vehicle.ID)
            For search = 1 To index
                  If Worksheets("VehID").Cells(search, 1) = ID1 Then
                        For col = 1 To 5
                              Worksheets("Port").Cells(i1, col).Value =
                              CLng(Worksheets("Master").Cells(search,
                              col).Value)
                        Next
                        i1 = i1 + 1
                  End If
            Next
      End If
Next
```

Figure 10: Script that Transfers Vehicles from VISSIM© to Arena© in the RTI.

The third, and last part of the model, is the federation interface. This section of the model is a Microsoft Excel© macro and can be found in its entirety in appendix A. The basic structure of the macro script is a continuous loop executed for the duration of the simulation period. This loop alternates simulation executions between

VISSIM© and Arena©, running VISSIM© for a time step, and then Arena© for the same time step. The VISSIM© time step is defined in the macro and the federation clock is synced to the simulation clock of VISSIM©.

The portion of the script that removes a vehicle in VISSIM© and recreates it in Arena© is located in Figure 10. The variable ‘vehicles2’ is a collection of vehicles located on link number 2. The script cycles through every vehicle starting at the beginning of the link (where the x-coordinate starts at 0). This is repeated for each VISSIM© link that interfaces with Arena©. For each vehicle, it checks to see if the vehicle is located within 25 meters of the end of the link, where the variable ‘length2’ in Figure 10 has been set to be the length of VISSIM link number 2. If there is a vehicle in the last 25 meters, the following line ‘s.VariableArrayValue(1) = 1’ triggers Arena’s SIMAN language and changes the value of variable number 1 to the value of 1, i.e., the previously defined switch variable for the appropriate port or distribution center gate. This is the cue that is sent to Arena© to create a vehicle at its respective location (i.e. that a truck is entering the port or distribution center from the roadway network), each location having a unique variable number. The variable, ‘ID1’, collects the ID of the vehicle being transferred. Once the identity of the vehicle is known, it is removed from VISSIM©.

If a vehicle is removed, the next nested loop in Figure 10 searches for the location in Excel© when this particular vehicle’s ID was written upon entry into the VISSIM network. This is done by searching through the worksheet in Excel© that collected all of the vehicle identification numbers upon creation of vehicles in VISSIM©. Once it is found, the record number (which is the corresponding Excel©

row number), is identical to the record number in the master database which contains all the Arena© attributes associated with this truck and the container it is carrying. These two record numbers are identical because every time an entity is written to the master database, a vehicle is created in VISSIM©, and its vehicle ID is written to the same field in a separate worksheet. This is depicted in steps 1 and 2 of the process shown in Figure 11. The information is then transferred to a unique worksheet corresponding to the location in Arena© in which the vehicle will be recreated and subsequently read from, as illustrated in step 3. The variable, ‘i1’, is the record number for the unique worksheet represented in step 3, and is only increased when information is added to this sheet, because Arena reads from a worksheet starting with record number 1 and advances one record number each time information is read.

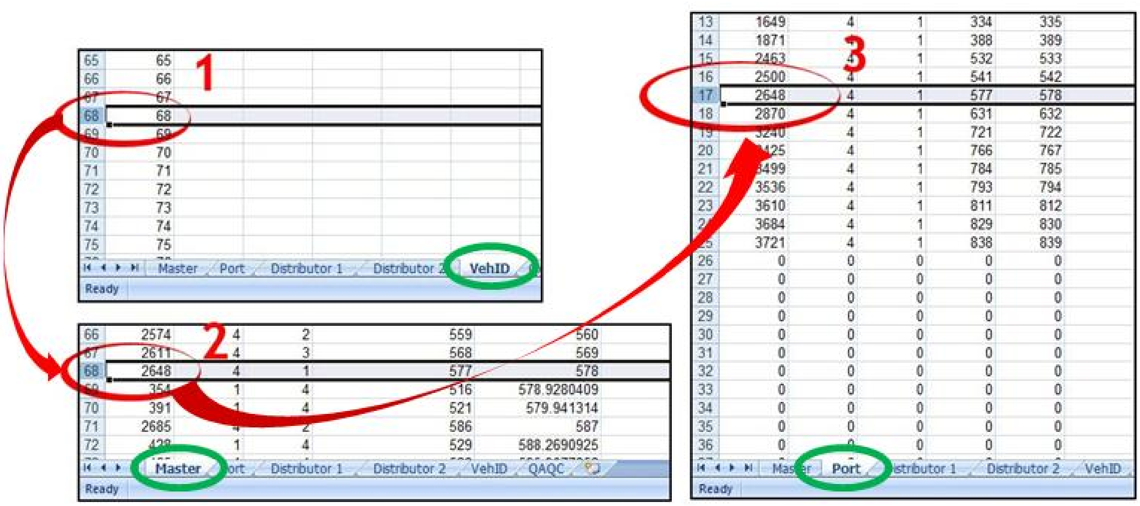

Figure 11: Illustration of how the Database is Processed and Managed.

The portion of the script that steps through Arena© and resets all of the dynamic variables is shown in Figure 12. The variable 'aTime' is set to the current time of the Arena© simulation clock and the variable 'fTime' is set to the time of the federation clock, which is synced to the VISSIM© simulation clock. The script continues to step through the Arena© simulation time until it reaches the VISSIM© simulation time. Once that condition is reached, all of the dynamic variables that could have been changed previously in the script to create entities in Arena are changed back to their initial state.

```
While Int(aTime) <= fTime
      m.Step
      m.Pause
      aTime = s.RunCurrentTime
Wend
s.VariableArrayValue(1) = 0
s.VariableArrayValue(2) = 0
s.VariableArrayValue(3) = 0
s.VariableArrayValue(4) = 0
```

Figure 12: Portion of the Script that Steps Through Arena© and Resets Dynamic Variables.

```
Do While entity > 0
      entity = Worksheets("Master").Cells(index, 1).Value
      If index > 1 Then
            If entity = Worksheets("Master").Cells(index - 1,
            1).Value & Worksheets("Master").Cells(index, 2) =
            Worksheets("Master").Cells(index - 1, 2) Then
                  Worksheets("Master").Cells(index, 1).Value = "##"
                  index = index + 1
                  Exit Do
            End If
      End If
      originID = Worksheets("Master").Cells(index, 2)
      destinationID = Worksheets("Master").Cells(index, 3)
      If entity > 0 Then
            If originID = 1 Then
                  linkNum = 39
            ElseIf originID = 2 Then
                  linkNum = 29
            ElseIf originID = 3 Then
                  linkNum = 77
            ElseIf originID = 4 Then
                  linkNum = 102
            ElseIf originID = 5 Then
                  linkNum = 76
            Else
                  linkNum = 50
            End If
            If destinationID = 1 Then
                  vehType = 100
            ElseIf destinationID = 2 Then
                  vehType = 200
            ElseIf destinationID = 3 Then
                  vehType = 300
            ElseIf destinationID = 5 Then
                  vehType = 800
            Else
                  vehType = 500
            End If
            Set vehicle =
            vissim.net.Vehicles.AddVehicleAtLinkCoordinate(vehType,
            50, linkNum, 1, 0)
            Worksheets("VehID").Cells(index, 1) = vehicle.ID
            Worksheets("VehID").Cells(index, 2) = fTime
            index = index + 1
      End If
Loop
```

Figure 13: Portion of the Script that Transfers Vehicles from Arena© to VISSIM©.

The section of the code that detects entities leaving Arena and creates corresponding vehicles entering VISSIM© is shown in Figure 13. The 'index' variable starts off at a value of 1 and increases every time a new entity's information is read from the master database in the Excel workbook. If there is a new creation in the database, its information is used to create a new vehicle in VISSIM. Given the origin and destination locations from the database (determined in the Arena© modules), all of the parameters for the create vehicle command may be determined. The command, with its parameters, are as follows, "AddVehicleAtLinkCoordinate(Vehicle Type, Desired Speed, Link Number, Lane Number, X-Coordinate, Interaction)" [12]. The vehicle type is derived from the variable 'destinationID' and the link number is derived from the variable 'originID'. The vehicle speed is set to 50 km/hr. Once created, the vehicle identification number is written to Excel©, in a vehicle ID worksheet, in the same row as the truck or containers Arena© attributes in the master database worksheet. This, again, is how the script executes the operation between 1 and 2 in Figure 11 and the two record numbers are kept identical.

2.2 Validating the Model

The purpose of the initial validation tests was to ensure the reasonableness and adequacy of the federation framework. Validation is a continual process, and validating this initial, basic model, attempts to ensure that the model is functioning properly [14]. In these tests, several different simulation runs are conducted and the results examined. The first three validation runs sent 100 trucks from the highway to the port, distributor 1, and distributor 2 respectively. A fourth validation run created 100 trucks where 50% are directed to the port and 25% each were sent to distributor 1 and 2 respectively. The fifth and sixth validation runs send a single truck to all locations in two different sequences. The results of these validation runs are presented in Table 1.

Table 1: Validation results of the basic federation model.

Run	Port		Distributor 1		Distributor 2		Highway	
	Arena	VISSIM	Arena	VISSIM	Arena	VISSIM	Arena	VISSIM
1	100	100	0	0	0	0	100	100
2	0	0	100	100	0	0	100	100
3	0	0	0	0	100	100	100	100
4	54	54	14	14	32	32	100	100
5	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1

In the basic model, all the truck traffic originates in the VISSIM© model; traffic may also depart from the VISSIM© model at the "highway" link, representing trucks leaving the area for long distance hauling. The totals in the Arena columns are recorded from two sets of counters, one set located in the *vehicle input* module, and the other located at the end of the model logic directly preceding the *dispose* blocks. An equal number of vehicles are recorded at both entrances and exits of Arena© in each validation run, which means that for every vehicle that enters a specific location in the Arena© model, another one leaves that same location and additional vehicles are neither created nor destroyed in the process. The totals in the VISSIM© columns are recorded by eight data collectors, two located at each of the four terminals of the basic model. In these tests, each pair of data collectors were also found to report an equal number of trucks, meaning that for every truck leaving the VISSIM© model, an equal number enter the VISSIM© network at the corresponding terminal. This implies that no vehicles are lost in the transition from VISSIM© to Arena© or from Arena© to VISSIM©.

In the first validation run, 100 trucks were created in Arena© at the highway, and all were directed towards the port. In each run, 100 trucks are initially created and travel on the highway, enter the port and leave some time later, returning to the highway. All 100 trucks were created in the first 15 minutes of the 45 minute simulation period to give ample time for every vehicle to complete its course through the model before the end of the simulation. This process was continued in two additional runs, where the 100 trucks are sent to distributor 1 only and distributor 2 only, respectively.

Validation run 4 was programmed to send 50% of the trucks generated to the Port, 25% to distributor 1 and 25% to distributor 2, and then have each truck return to the highway for long distance hauling. Arena© uses an algorithm to decide which vehicles go to which destination, and therefore the actual vehicle volumes are determined by a stochastic process. Since this was a test to ensure the model can handle scenarios where trucks will have different origin-destination pairs, the precision of assignment percentages in Arena© is not important. According to the results, over half of the vehicles do go to the port, approximately an eighth go to distributor 1 and approximately a third go to distributor 2. In addition to using validation 4 to check vehicle totals, the model outputs were checked to ensure that vehicles are properly directed to their correct destinations.

This validation process follows the mapping procedure outlined in Figure 11. Each entity listed in the master database should also appear in its respective sub-database specific to its destination ID. In the sub-databases, entities should be recorded in order of their arrival at the destination, which may not necessarily be the same order as their departure from their trip origin. Timestamps are included with every entry from Arena and VISSIM© and can be used to determine that all activity is occurring at its proper time. The outputs of this validation run are presented in Appendix B.

2.3 Applying the Conceptual RTI

The principal ideas learned from a basic federation between Arena© and VISSIM©, can now be applied to a more realistic and more complex model of the Port of Savannah and the surrounding roadway network. A pre-existing model of the Port of Savannah in Arena© and a separately created model of the roadway network in VISSIM© were federated. The pre-existing Arena© model uses transporters to move the containers between the port and the distribution centers. These transporters will be replaced with the VISSIM© model, and several interfaces between the two models will be created. A flowchart of the complete federation is outlined in Figure 14.

There are five transfers between Arena© and VISSIM© in the Port of Savannah model, and they are marked by pairs of opposing arrows. There is one located at a gate at the port, one at each of three distribution centers, and one at an access point to Interstate 16, labeled "Highway." The intersection marked on the map is the intersection of Bourne Avenue and Highway 21. The dashed line represents the boundary between the Arena© and VISSIM© domains.

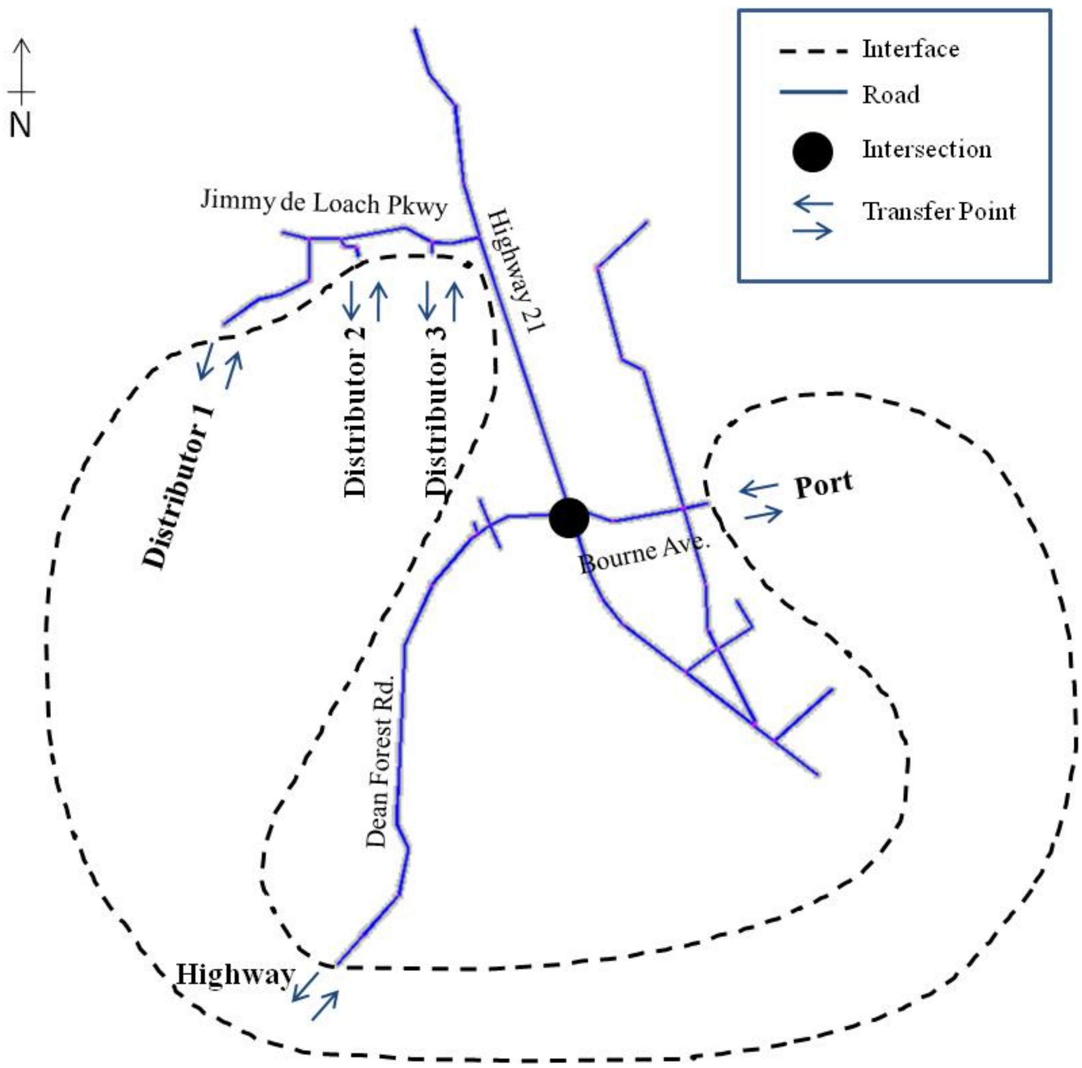

Figure 14: Map of the Federation between the Arena© Model and the VISSIM© Model.

The roadway depicted in Figure 14 is the actual VISSIM© network used. Background traffic is generated from four locations on the map. There is a signalized intersection located at Bourne Ave. and Highway 21. For a majority of the network, the roads are two lanes in each direction. Trucks carrying containers are generated in Arena© and are placed into the VISSIM© network at the highway interface location. This is the main source of the truck supply for the port. Routing decisions are used in VISSIM© to direct each truck to its appropriate destination, as was done in the basic federated model. Six vehicle classes were used in this case, instead of the four used in the basic federation. This is due to the increase in locations included in the federation.

The entities in this Arena© port simulation model represent containers, and information on each is written to Excel© when the container passes through the interface. The most important attributes recorded are unique container ID number, its origin and destination, the time it was first introduced into the Arena© model, and the final time when it is exited the Arena© model. These attributes are later read by Arena© when the container makes its return back into the Arena© model. These attributes are tied to the unique vehicle number assigned to each vehicle in the VISSIM© network. The same bookkeeping principles were used in this federation as they were in the basic federated model.

Trucks are not directly modeled in the large port model in Arena©. The original Arena© model used transporters to represent trucks, however, these were not able to be utilized in the federated model as they were not dynamically editable through COM. Thus, for the federated model, an index was created in the Arena© model that maintained a record of the number of trucks that would be available given the current container movements. This index increases when a container would no longer require a truck, and decreases when a container requires a truck to be transported. If the truck availability index is zero, the container is held in a queue until one becomes available. Each location has its own index of available truck.

2.4 Chapter Summary

The methodology from concept to fruition has been described. An initial simplistic Arena© model was federated with a simple four-approach intersection in VISSIM©. This simple system of federates was validated to ensure the federation framework was adequate and was functioning properly. The lessons learned through the process of creating a simplistic federated system was applied to creating a more detailed system of the Port of Savannah. The results of this system are presented in Chapter 3 and are discussed in Chapter 4.

CHAPTER 3

RESULTS

To demonstrate the advantages of running a federated simulation between VISSIM© and Arena©, rather than a single monolithic model, several experiments are designed. The results of these experiments will outline how each federate affects the other. The performance measures of the system will include delays experienced by the trucks on the roadway network, delays experienced by the containers at each location, and the average number of trucks available (as a resource) at each location.

In an ideal situation, the model would be tested against real world data to ensure its accuracy. However, since real-world data is not readily available, a sampling of vehicle volumes and container volumes are used as a base study [14]. This selection did not alter the purpose of this research, since the experiments were chosen to demonstrate the flexibility and the interaction between the two federates within the model. The experiments are designed to observe how alterations in one federate (i.e. the VISSIM© model) will affect the other federate (i.e. the Arena© model).

The study consists of an analysis of four different scenarios, a base model and 3 experimental changes to the base model, to explore how different variations of vehicular traffic and container traffic affect each other. As discussed earlier, vehicles are introduced at four locations in the VISSIM© model. For the base model simulation runs, a stochastic volume of 500 vehicles was introduced at each input, serving as background roadway traffic. Containers are introduced into the Arena©

model in three locations, coming off ocean going vessels, coming off trains, and coming from long distance hauling. In the port model, there are six berths for vessels to dock, with each vessel offloading between 25 and 75 containers (determined according to a uniform distribution), with a similar number to be loaded onto each ship prior to departure. Container arrival times from long distance trucking are modeled using an exponential distribution based on multiple parameters.

The first experiment was designed to increase the base model background traffic volumes on the roadway network surrounding the port. In this test, the vehicle volumes are increased by 500% compared to the base case. This experiment is designed to determine how the port model will be impacted by the additional delays on the roadway network. This will be done by comparing the average time spent in the port by containers in this experiment to the base case simulations.

The second experiment was designed to increase the volume of container traffic through the port. This was simulated by duplicating containers as they came off of the ocean going vessels, and reassigning the duplicates with a new unique identifier. This essentially doubled the number of containers received from ships. This model explores how the roadway network reacts to demand changes from the port model. This experiment examines how the roadway network is impacted by increased port traffic, including an examination of any additional delays experienced by the containers on the port, and the factors contributing to this delay.

The third experiment combines the increase of container traffic through the port and the increase of vehicular traffic volume in the surrounding roadway network in the same manner that was undertaken in experiment1 and experiment 2.

For each experiment and the base case, three replicate trials were simulated. The random number seeds used in the replicate trials were kept constant between the experiments, but varied between the replicate runs. The random number seeds determine the stochasticity of the model and lead to variability among the results. Table 2 shows the random number seeds used for each experimental run. Table 3 shows the initial truck conditions for each of the model runs.

Table 2: Random Seed Numbers used in the Simulations

	Replicate Run 1	Replicate Run 2	Replicate Run 3
VISSIM	174	395	280
Arena	14561	3579	1234

Table 3: Number of Trucks at Commencement of Simulation

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	30	30	30	30
Distributor 1	0	0	0	0
Distributor 2	0	0	0	0
Distributor 3	0	0	0	0

3.1 Base Case Model

The base case simulation provides a reference point from which one may explore how variations in certain parameters will affect the outputs of the model. For each base case replicate run, an input of 500 vehicles is entered into the model at four locations in the VISSIM© model. Three replicates of the base case model are simulated using three different random number seeds (Table 2), and the results are presented in Tables 4 through 8.

Table 4: Average Time (min) Spent by the Containers at each Location for the Base Case Model

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	74.8	86.3	87.1	82.7
Distributor 1	3.2	3.1	3.1	3.1
Distributor 2	3.1	3.1	3.0	3.1
Distributor 3	3.1	3.1	3.0	3.1

Table 5: Average Travel Time (min) between Locations for the Base Case Model

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port → Distributor 1	13.5	13.6	13.6	13.6
Port → Distributor 2	11.2	11.1	11.1	11.1
Port → Distributor 3	9.1	9.1	9.1	9.1
Distributor 1 → Port	24.5	23.5	24.1	24.0
Distributor 2 → Port	21.3	21	20.8	21.0
Distributor 3 → Port	19	18.6	18.8	18.8

Table 6: Average Number of Trucks Available at each Location for the Base Case Model

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	112.89	116.63	38.33	89.29
Distributor 1	64.54	13.20	20.84	32.86
Distributor 2	11.18	13.58	13.82	12.86
Distributor 3	14.10	14.63	18.33	15.69

Table 7: Percentage of Containers that Left the Port for the Base Case Model

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	97.5%	97.5%	99.6%	98.2%

Table 8: Average Queue Length (ft) at the Intersection of Bourne Ave & Hwy. 21 for the Base Case Model

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
NB	1	1	1	1.0
SB	2	3	5	3.3
EB	2	2	2	2.0
WB	0	0	0	0.0

The results in Table 4, the average time spent by each container at each location, are tabulated by calculating the average time spent in a particular location. The calculations from the port are determined for all containers coming off the vessels and destined for a location outside the port requiring truck transport. The calculations from the local distribution centers are a simple average of the time spent by each container at each location.

The results in Table 5, the average travel time between locations, are directly measured from the outputs of the VISSIM© model. The difference in time from the timestamps created when vehicles entered and exited the VISSIM© model is averaged for each origin-destination pair.

The results in Table 6 show the availability of trucks at each location. An available truck is defined as a truck that has an empty chassis and is waiting for a container to be loaded onto it. At each timestep, the number of trucks available at each location is written to an Excel© spreadsheet. These values are averaged over the entire time period of eight hours.

The results in Table 7 shows the percentages of containers that leave the port compared with the total number of containers that enter the port from the vessels. In all experiments, there will be a number of containers that will not leave the port by the time the simulation is over, as containers that are unloaded from the ship near the end of the simulation time period may not have sufficient time to be loaded on a truck and leave the port. However, this is a measure that may be used to determine if port or roadway congestion results in additional containers being unable to leave the port. A decrease in this measure translates into an increase in temporarily stored containers on the port, which will require more space allocated at the port.

The same procedure was be used to calculate the results in experiments one, two, and three. These results will be presented in subsequent sections in this chapter and discussed in the next chapter.

3.2 Experiment One: Increased Traffic Conditions

The parametric changes in experiment 1 regard increases in the background traffic volume on the roadway network in VISSIM only. The results for this experiment are presented in Tables 9 through 13.

Table 9: Average Time (min) Spent by the Containers at each Location for Experiment One

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	106.3	73.2	101.3	93.6
Distributor 1	3.1	3.0	2.9	3.0
Distributor 2	3.0	3.1	3.1	3.1
Distributor 3	3.0	3.0	3.0	3.0

Table 10: Average Travel Time (min) between Locations for Experiment One

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port → Distributor 1	83	81.7	87.8	84.2
Port → Distributor 2	80.2	81.7	87.6	83.2
Port → Distributor 3	85.8	80.1	84.6	83.5
Distributor 1 → Port	167.3	159.3	200.6	175.7
Distributor 2 → Port	144.8	140	182.7	155.8
Distributor 3 → Port	72.6	81.2	86.4	80.1

Table 11: Average Number of Trucks Available at each Location for Experiment One

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	5.00	26.40	8.66	13.35
Distributor 1	7.70	4.17	5.18	5.68
Distributor 2	3.72	4.56	7.19	5.16
Distributor 3	4.49	6.29	9.44	6.74

Table 12: Percentage of Containers that Left the Port for Experiment One

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	91.6%	97.5%	91.1%	93.4%

Table 13: Average Queue Lengths (ft) at the Intersection of Bourne Ave & Hwy 21 for Experiment One

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
NB	145	146	145	145.3
SB	99	112	101	104.0
EB	114	123	116	117.7
WB	0	0	0	0.0

3.3 Experiment Two: Increased Container Volumes at the Port

The parametric changes in experiment 2 involve the increasing of container volumes through the port of Savannah coming off of vessels only. The results of this experiment are shown in Tables 14 through 20.

Table 14: Average Time (min) Spent by the Containers at each Location for Experiment Two

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	67.9	83.5	110.0	87.1
Distributor 1	3.0	3.1	3.1	3.1
Distributor 2	3.0	3.0	3.2	3.1
Distributor 3	3.0	3.0	3.1	3.0

Table 15: Average Travel Time (min) between Locations for Experiment Two

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port → Distributor 1	13.8	13.6	13.6	13.7
Port → Distributor 2	11.2	11.2	11.2	11.2
Port → Distributor 3	9.4	9.3	9.2	9.3
Distributor 1 → Port	23.6	24	23.5	23.7
Distributor 2 → Port	21.1	21.8	21.2	21.4
Distributor 3 → Port	19.8	19.1	19.2	19.4

Table 16: Average Number of Trucks Available at each Location for Experiment Two

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	40.79	30.77	14.40	28.65
Distributor 1	26.17	26.75	29.09	27.34
Distributor 2	20.49	24.20	31.56	25.42
Distributor 3	14.19	25.76	37.59	25.84

Table 17: Percentage of Containers that Left the Port for Experiment Two

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	78.1%	86.6%	78.2%	81.0%

Table 18: Average Queue Length (ft) at the Intersection of Bourne Ave & Hwy 21 for Experiment Two

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
NB	1	1	1	1.0
SB	2	7	7	5.3
EB	2	2	2	2.0
WB	0	0	0	0.0

3.4 Experiment Three: Increases in Traffic Volume & Container Volume

The parametric changes in experiment 3 include both increases to background traffic volume and increases to the container volume coming through the port of Savannah through vessels only. The results of this experiment are presented in Tables 19 through 23.

Table 19: Average Time (min) Spent by the Containers at each Location for Experiment Three

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	191.1	104.5	144.4	146.7
Distributor 1	2.9	3.0	2.8	2.9
Distributor 2	3.0	3.0	3.0	3.0
Distributor 3	2.9	2.9	3.0	2.9

Table 20: Average Travel Time (min) between Locations for Experiment Three

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port → Distributor 1	81.4	86.1	82.9	83.5
Port → Distributor 2	77.2	81.6	81.2	80.0
Port → Distributor 3	75.9	83.8	77	78.9
Distributor 1 → Port	159.7	177.7	166.1	167.8
Distributor 2 → Port	141.2	147.7	150.7	146.5
Distributor 3 → Port	85.4	82.8	81.9	83.4

Table 21: Average Number of Trucks Available at each Location for Experiment Three

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	0.76	1.38	0.51	0.88
Distributor 1	13.49	5.81	8.24	9.18
Distributor 2	6.17	9.57	5.86	7.20
Distributor 3	5.35	13.52	9.11	9.33

Table 22: Percentage of Containers that Left the Port for Experiment Three

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
Port	52.2%	65.1%	54.6%	57.3%

Table 23: Average Queue Length (ft) at the Intersection of Bourne Ave & Hwy 21 for Experiment Three

	Replicate Run 1	Replicate Run 2	Replicate Run 3	AVG
NB	145	145	145	145.0
SB	109	113	105	109.0
EB	106	121	120	115.7
WB	0	0	0	0.0

3.5 Chapter Summary

The federated system has now been tested in four different scenarios: the base case scenario, an increase in vehicular traffic in the VISSIM© federate, an increase in container volume in the Arena© federate, and increases to both vehicular traffic and container volume. Vehicular traffic inputs in VISSIM© were increased from 500 vehicles to 2,500 vehicles at four different locations in the network. Container volumes were doubled coming off of ocean going vessels in Arena©. Each experiment was replicated three times and run for a simulation period of eight hours. The results have been presented in this chapter and will be discussed in Chapter 4.

CHAPTER 4

DISCUSSION OF RESULTS AND CONCLUSION

The results presented in Chapter 3 will be discussed and compared in this chapter. Tables 24 through 28 compare all of the results from experiments 1 through 3 against the baseline scenario. Tables 24 through 27 give the percent change between experiments 1 through 3 and the baseline scenario. Table 28 is a simple difference of the queue lengths at Bourne Ave. and Highway 21, measured in feet, comparing experiments 1 through 3 and the baseline scenario.

Table 24: Percent Change of the Average Time Spent by the Containers at each Location

	Experiment		
	1	**2**	**3**
Port	13.12%	5.30%	77.25%
Distributor 1	-4.26%	-2.13%	-7.45%
Distributor 2	0.00%	0.00%	-2.17%
Distributor 3	-2.17%	-1.09%	-4.35%

Table 25: Percent Change of the Travel Time between each Location

	Experiment		
	1	2	3
Port → Distributor 1	520.39%	0.74%	515.23%
Port → Distributor 2	647.01%	0.60%	618.56%
Port → Distributor 3	817.58%	2.20%	767.03%
Distributor 1 → Port	631.21%	-1.39%	598.34%
Distributor 2 → Port	640.89%	1.58%	596.67%
Distributor 3 → Port	325.89%	3.01%	343.44%

Table 26: Percent Change of the Average Number of Available Trucks at each Location

	Experiment		
	1	2	3
Port	-85.04%	-67.91%	-99.01%
Distributor 1	-82.70%	-16.80%	-72.07%
Distributor 2	-59.90%	97.63%	-44.02%
Distributor 3	-57.04%	64.74%	-40.56%

Table 27: Percent Change of the Number of Containers that Left the Port

	Experiment		
	1	2	3
Port	-4.89%	-17.55%	-41.65%

Table 28: Change (ft) in Average Queue Length at the Intersection of Bourne Ave & Hwy 21

	Experiment		
	1	**2**	**3**
NB	1	2	3
SB	144	0	144
EB	101	2	106
WB	116	0	114

4.1 Discussion of Experiment 1

From the results, it is seen that as the background traffic increases in the VISSIM© model, it impedes the flow of trucks traveling between the Port of Savannah and the local distribution centers. This becomes apparent by observing the travel times recorded by the trucks in experiment 1. These travel times are found to be, on average, nearly six times longer than the travel times in the base case scenario. The increase in travel time is one measure of this congestion, but also an increase in the average queue lengths at Bourne Ave. and Highway 21 further confirms the increasing level of congestion. These queues increased from an average of 1 foot to 144 feet. The increased congestion diminishes the supply of trucks at the port to service the transport of containers between locations, as trucks are trapped in the roadway congestion. This impact is apparent in the measure of available trucks at each location. There is an 85% reduction in the average number of available trucks at the Port of Savannah when traffic on the surrounding roadway network is congested. This congestion results in an overall delay of the containers waiting to leave the Port of Savannah, which on average takes 13% longer than when there is less congestion in the surrounding roadway network as during the base case scenario.

This congestion in the surrounding roadway network does, in fact, impede the operations of the Port of Savannah. Consequences of the diminished supply of trucks as a resource will require the Port of Savannah to provide additional space to store containers waiting for transport outside of the port or additional roadway capacity in the surrounding area.

4.2 Discussion of Experiment 2

As the number of containers entering the Port of Savannah doubles, the available truck stocks are depleted at a much faster rate. The experiment outputs show a significant decline in the average number of available trucks, with a reduction of 68% at the port. This resulted in an average 5.3% increase in the amount of time each container spent at the port compared with the base case scenario. The cause of this reduction is based almost entirely on their being an inadequate number of available trucks to service the higher container demand. There is no significant difference between the travel times between experiment 2 and the base case scenario, as is shown in Table 25, with an average of 1.12% increase in travel times. There are also no significant differences in average length of the queues measured at the intersection at Bourne Ave. and Highway 21, shown in Table 28.

However, in replicate 1 of experiment 2, there is an inconsistent decrease in the time spent by the containers at the Port of Savannah. An explanation of this situation is a result of the nature of the variability of the ship arrival times, which leads to variations in the container arrivals at the port. These different variations could lead to varying results. Periods of inactivity in the port could lead to excessive amounts of unused resources, where a more steady cycle would be more consistent in utilizing these resources.

Figures 15 and 16 show the cycles of replicates 1 and 3 respectively for experiment 2. The container points represent discrete arrivals of vessels with the number of containers each of those vessels are carrying. The trucks line represents the fluctuation of the number of trucks at the port at any given time.

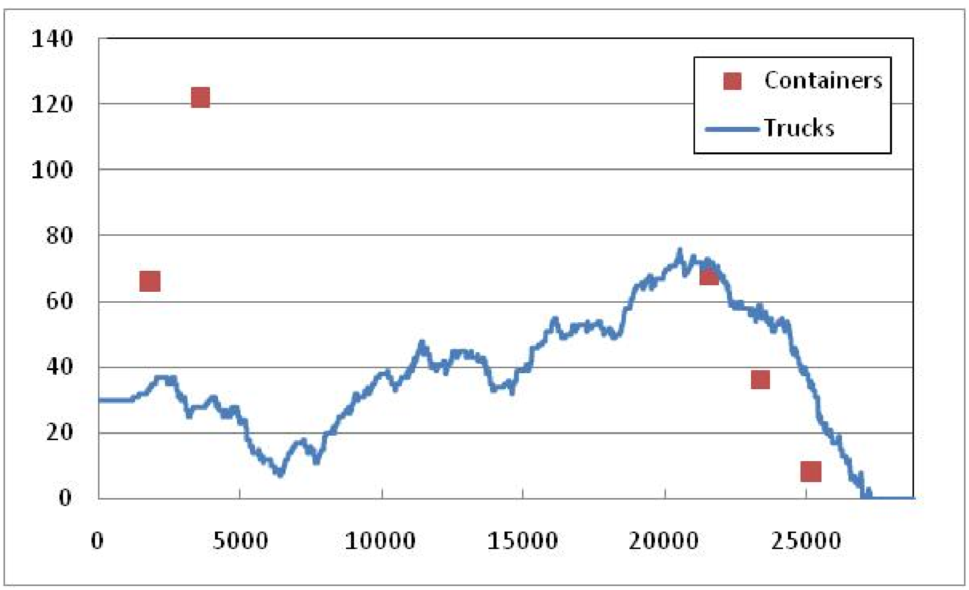

Figure 15: Arrival Pattern of Trucks and Containers at the Port of Savannah for Run 1 of Experiment 2.

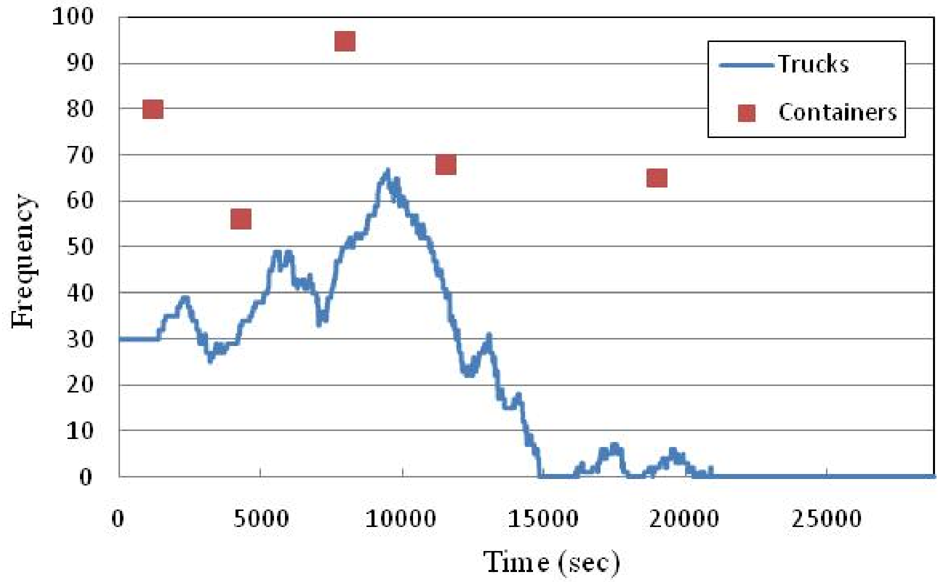

Figure 16: Arrival Pattern of Trucks and Containers at the Port of Savannah for Run 3 of Experiment 2.

Based on Figure 16, the arrival pattern of vessels entering the Port of Savannah is relatively uniform and there is a distinct cyclic pattern of truck availability at the port. Figure 15, alternatively, has a more scattered arrival pattern of vessels entering the port, resulting in a quickly diminishing supply of trucks followed by a slow buildup of available trucks due to a sustained period without new ship arrivals. This buildup creates a situation where containers do not have to wait for a truck to become available, and can be immediately dispatched to their destinations outside the port. However, near the end of the simulation three ships arrive in quick succession, rapidly depleting the available trucks. It is expected that if the simulation was run for a longer time frame, the container delays may significantly increase.

Overall, the containers spend 5% more time at the port than in the base case scenario. With this additional delay at the port of Savannah, there is an 18% decline in the number of containers that are leaving the port compared with the baseline scenario.

4.3 Discussion of Experiment 3

Experiment 3 combined the increases of vehicular traffic in the VISSIM© network (Experiment 1) and of the containers arriving by ship (Experiment 2). As significant impedances are observed in experiments 1 and 2, the results in experiment 3 should be more significant when the two factors are combined.

An impedance in the supply of trucks arriving at the port is created by the congestion on the roadway network. The delay at the port is exacerbated by the high volume of containers coming through the port from the cargo vessels. The relatively low supply of trucks is used at quicker pace than in experiments 1 and 2. There is a 99% reduction in the availability of trucks at the port compared with 85% and 68% in experiments 1 and 2 respectively.

This serious decline in the number of trucks at the port, available to transport the containers, leads to a significant increase in the amount of time the containers spend at the port. This dwell time rose by 77%, relative to the base case, compared to 13% and 5% for experiments 1 and 2 respectively. This additional delay resulted in a large increase in the number of containers that did not leave the port in the same eight hour period as the base case scenario. Of the containers that came through the Port of

Savannah during the simulation period, there is a 42% decline in the number of the containers that were able to obtain a truck and transport them to locations outside the port. This is a much larger decline than the 5% observed in experiment 1 and 18% in experiment 2.

There are no significant increases in travel time between experiment 3 and experiment 1, where background traffic was increased to congested conditions. Travel times for experiment 3 were also on average nearly six times longer than those in the base case scenario. The queue lengths at the intersection of Bourne Ave and Highway 21 also remained relatively consistent between experiments 1 and 3.

4.4 Conclusions

The results from the simulation experiments make it apparent that federating between VISSIM© and Arena© produce a unique ability to capture the interactions between the port and the roadway network. This is most apparent in experiments 1 and 3, where the increase in VISSIM© traffic significantly increases delays experienced by the containers at the Port of Savannah.

The results also make it clear that trucks are the limiting factor in the overall operations of the Port of Savannah. The results show that delay at the port is directly related to the availability of trucks at the port. The results also show, with an increase in travel time between local distribution centers and the port, there is a decrease in the availability of trucks.

The decrease in available trucks is also a determining factor for the increase in containers being temporarily stored at the port waiting for transport to other locations. This could be potentially burdensome for ports, especially the Port of Savannah, where the container traffic through the port is expected to increase. In experiment 3, a large percentage of the containers are expected to need temporary storage while they wait to be transported. This means the port will need to allocate additional space, in what is predicted to be an increasingly congested port, to store containers.

As seen in experiment 2, the unique arrival patterns produced in the discrete model severely impacted the conditions in the continuous simulator. This is an additional benefit of federating the two disparate simulators. Cyclical arrival patterns are not always consistent and are therefore not predictable, and alterations can severely impact the system, as shown in replicate 1 of experiment 2.

After looking at all of the results, it was determined that the Port of Savannah model did not reach stead state by the end of the simulation period of eight hours. As shown in Figures 15 and 16, the variability in the arrival patterns of ships affected the results of these simulations severely. It is very likely that the time spent by the containers at the port in replicate 1 in experiment 2 will begin to increase, as the truck availability approached zero near the end of the simulation period.

The benefits of running these two models concurrently are apparent in the results of the model. Arena©, which is used as a discrete logistics model, will not be able to appropriately simulate the conditions of the roadway network, and therefore not be able to produce realistic travel time results between the port and local distribution centers. VISSIM© on the other hand, is not capable of modeling the operations of the port. By federating the two models, the federated system capitalizes on the strengths of each.

CHAPTER 5

RECOMENDATIONS

The principles of this research can lead the way towards future applications in the field of transportation engineering, especially those involving a multi-modal system. This prototype can also lead towards creating a true transportation run-time infrastructure that is HLA-compliant, and capable of federating transportation simulation models.

It is reasonable to say that the principles of this research are not unique to the Port of Savannah. For example, all seaports are multi-modal systems, and this prototype can be applied to any seaport around the world to model their entire system of operations. Integrating existing port models with arterial network models can provide a complete overview of the system.

In addition to seaports, any system with two or more behaviorally different functional areas that interact could benefit from this research. A second example could be a comprehensive airport model. Plane arrival and departures could be modeled using an air side simulator, the gateside or plane unloading modeled with a pedestrian type simulator, and the roadway network modeled in a transportation simulator. As the number of planes, passengers, or cargo increase at an airport, the impact on the roadway network around the airport could be captured. This interaction would be difficult to capture in independent runs of independent models, nor would all components be able to be simulated in a single monolithic model.

The primary purpose of this effort was to show that Arena© and VISSIM© can run concurrently with one another. There are many improvements that should be made to this federated model. Specific to the Port of Savannah, the model should be improved to include all of the gates at the port, additional distributional centers, a rail model with additional rail cargo yards, and the inclusion of the local airport. The logistics of each of the distribution centers can also be implemented to provide a more realistic model of operations.

This model is a prototype and its future applications are very important to this research. This model could be easily modified and adapted to changing conditions. The user-created modules make it easy to add multiple transition locations between models. This is one of the primary principles of HLA, which is to promote interoperability and reusability [7].

Several limitations do exist in this federation that will need to be rectified in continued research of federating disparate simulators. Of significant concern is the possibility that queues might spillback from one federate into the other. A transportation RTI will need to be able to detect queues and keep entities in one federate until access the other federate exists. For example, at the Port of Savannah it is possible that truck queues at the gate entrances might be sufficiently long to impact the VISSIM© network. However, this spillback would not be captured, with the VISSIM© model assuming truck departures immediately enter the port.

APPENDIX-A

```
Private Sub CommandButton1_Click()

Dim m As Model
Dim s As SIMAN
Dim vissim As vissim
Dim simulation As simulation
Dim net As net
Dim vehicle As vehicle
Dim links As links
Dim link49 As link  'Port
Dim link38 As link  'Distributor 1
Dim link28 As link  'Distributor 2
Dim link19 As link  'Distributor 3
Dim link75 As link  'Highway
Dim link101 As link 'CSX
Dim vehicles49 As Vehicles
Dim vehicles38 As Vehicles
Dim vehicles28 As Vehicles
Dim vehicles19 As Vehicles
Dim vehicles75 As Vehicles
Dim vehicles101 As Vehicles
Dim Time As Long
Dim aTime As Long
Dim fTime As Long
Dim ID1 As Long
Dim ID2 As Long
Dim ID3 As Long
Dim ID4 As Long
Dim ID5 As Long
Dim length49 As Long
Dim length38 As Long
Dim length28 As Long
Dim length19 As Long
Dim length75 As Long
Dim length101 As Long
Dim i1 As Long
Dim i2 As Long
Dim i3 As Long
Dim i4 As Long
Dim index As Long
Dim search As Long
Dim entity As Long
Dim destinationID As Long
Dim originID As Long
Dim linkNum As Long
Dim vehType As Long
Dim col As Long
Dim portTrucks As Long
Dim csxTrucks As Long
Dim dist1Trucks As Long
Dim dist2Trucks As Long
Dim dist3Trucks As Long
Dim runs As Long
```

```
Set vissim = CreateObject("vissim.vissim")
vissim.LoadNet ("C:\Documents and Settings\gtg418r\Desktop\Savannah
Port Federation\savannahRun1.inp")
Set m = Arena.ActiveModel
Set s = m.SIMAN
Set simulation = vissim.simulation
simulation.Period = 28800
simulation.Resolution = 1
simulation.Speed = 1000
simulation.RandomSeed = Worksheets("VISSIM").Cells(12, 4)

Set links = vissim.net.links
Set link49 = links.GetLinkByNumber(49)
Set link38 = links.GetLinkByNumber(38)
Set link28 = links.GetLinkByNumber(28)
Set link19 = links.GetLinkByNumber(19)
Set link75 = links.GetLinkByNumber(75)
Set link101 = links.GetLinkByNumber(101)

length49 = link49.AttValue("LENGTH")
length38 = link38.AttValue("LENGTH")
length28 = link28.AttValue("LENGTH")
length19 = link19.AttValue("LENGTH")
length75 = link75.AttValue("LENGTH")
length101 = link101.AttValue("LENGTH")
aTime = 0
fTime = 0

ID1 = 0
ID2 = 0
ID3 = 0
ID4 = 0
ID5 = 0
variable12 = 0
variable13 = 0
variable14 = 0
variable21 = 0
variable24 = 0
variable31 = 0
variable34 = 0
variable41 = 0
variable42 = 0
variable43 = 0
i1 = 1
i2 = 1
i3 = 1
i4 = 1
index = 1
Worksheets("Master").[A1:I5000].Value = 0
Worksheets("Port").[A1:I5000].Value = 0
Worksheets("Distributor 1").[A1:I5000] = 0
Worksheets("Distributor 2").[A1:I5000] = 0
Worksheets("Distributor 3").[A1:I5000] = 0
Worksheets("CSX").[A1:I5000] = 0
Worksheets("VehID").[A1:C5000] = ""
```

```
portTrucks = 0
csxTrucks = 0
dist1Trucks = 0
dist2Trucks = 0
dist3Trucks = 0

For Time = 1 To simulation.Period
      simulation.RunSingleStep
      fTime = vissim.simulation.AttValue("ELAPSEDTIME")
      Set vehicles49 = link49.GetVehicles
      Set vehicles38 = link38.GetVehicles
      Set vehicles28 = link28.GetVehicles
      Set vehicles19 = link19.GetVehicles
      Set vehicles75 = link75.GetVehicles
      Set vehicles101 = link101.GetVehicles
      For Each vehicle In vehicles49
            If vehicle.AttValue("LINKCOORD") > (length49 - 25) Then
                  s.VariableArrayValue(2000) = 1
                  ID1 = vehicle.ID
                  vissim.net.Vehicles.RemoveVehicle (vehicle.ID)
                  For search = 1 To index
                        If Worksheets("VehID").Cells(search, 1) =
                        ID1 Then
                              For col = 1 To 5
                                  Worksheets("Port").Cells(i1,
                                  col).Value =
                                  Worksheets("Master").Cells(searh,
                                  col).Value
                              Next
                              Worksheets("VehID").Cells(search, 3) =
                              fTime
                              i1 = i1 + 1
                        End If
                  Next
            End If
      Next
      For Each vehicle In vehicles38
            If vehicle.AttValue("LINKCOORD") > (length38 - 25) Then
                  s.VariableArrayValue(1010) = 1
                  ID2 = vehicle.ID
                  vissim.net.Vehicles.RemoveVehicle (vehicle.ID)
                  For search = 1 To index
                        If Worksheets("VehID").Cells(search, 1) =
                        ID2 Then
                              For col = 1 To 5
                                  Worksheets("Distributor
                                  1").Cells(i2, col).Value =
                                  Worksheets("Master").Cells(search,
                                  col).Value
                              Next
                              Worksheets("VehID").Cells(search, 3) =
                              fTime
                              i2 = i2 + 1
                         End If
                  Next
```

```
        End If
Next
For Each vehicle In vehicles28
        If vehicle.AttValue("LINKCOORD") > (length28 - 25) Then
                s.VariableArrayValue(1020) = 1
                ID3 = vehicle.ID
                vissim.net.Vehicles.RemoveVehicle (vehicle.ID)
                For search = 1 To index
                        If Worksheets("VehID").Cells(search, 1) =
                        ID3 Then
                                For col = 1 To 5
                                    Worksheets("Distributor
                                    2").Cells(i3, col).Value =
                                    Worksheets("Master").Cells(search,
                                    col).Value
                                Next
                                Worksheets("VehID").Cells(search, 3) =
                                fTime
                                i3 = i3 + 1
                        End If
                Next
        End If
Next
For Each vehicle In vehicles19
        If vehicle.AttValue("LINKCOORD") > (length19 - 25) Then
                s.VariableArrayValue(1030) = 1
                ID4 = vehicle.ID
                vissim.net.Vehicles.RemoveVehicle (vehicle.ID)
                For search = 1 To index
                        If Worksheets("VehID").Cells(search, 1) =
                        ID4 Then
                                For col = 1 To 5
                                    Worksheets("Distributor
                                    3").Cells(i4, col).Value =
                                    Worksheets("Master").Cells(search,
                                    col).Value
                                Next
                                Worksheets("VehID").Cells(search, 3) =
                                fTime
                               i4 = i4 + 1
                        End If
                Next
        End If
Next
For Each vehicle In vehicles75
        If vehicle.AttValue("LINKCOORD") > (length75 - 25) Then
                ID5 = vehicle.ID
                vissim.net.Vehicles.RemoveVehicle (vehicle.ID)
                For search = 1 To index
                        If Worksheets("VehID").Cells(search, 1) =
                        ID5 Then
                                Worksheets("VehID").Cells(search, 3) =
                                fTime
                        End If
                Next
```

```
		End If
	Next
	While Int(aTime) <= fTime
		m.Step
		aTime = s.RunCurrentTime
	Wend
	Worksheets("Outputs").Cells(fTime + 1, 1) = fTime
	Worksheets("Outputs").Cells(fTime + 1, 2) =
	s.CounterValue(3000)
	Worksheets("Outputs").Cells(fTime + 1, 3) =
	s.CounterValue(1000)
	Worksheets("Outputs").Cells(fTime + 1, 4) =
	s.CounterValue(2000)
	Worksheets("Outputs").Cells(fTime + 1, 6) =
	s.VariableArrayValue(10000)
	Worksheets("Outputs").Cells(fTime + 1, 7) =
	s.VariableArrayValue(20000)
	Worksheets("Outputs").Cells(fTime + 1, 8) =
	s.VariableArrayValue(30000)
	Worksheets("Outputs").Cells(fTime + 1, 9) =
	s.VariableArrayValue(40000)
	Worksheets("Outputs").Cells(fTime + 1, 10) =
	s.VariableArrayValue(50000)
	Worksheets("Outputs").Cells(fTime + 1, 11) =
	s.VariableArrayValue(60000)
	s.VariableArrayValue(1010) = 0
	s.VariableArrayValue(1020) = 0
	s.VariableArrayValue(1030) = 0
	s.VariableArrayValue(2000) = 0
	entity = 1
	Do While entity > 0
		entity = Worksheets("Master").Cells(index, 1).Value
		If index > 1 Then
			If entity = Worksheets("Master").Cells(index - 1,
			1).Value & Worksheets("Master").Cells(index, 2) =
			Worksheets("Master").Cells(index - 1, 2) Then
				Worksheets("Master").Cells(index, 1).Value =
				"##"
				index = index + 1
				Exit Do
			End If
		End If
		originID = Worksheets("Master").Cells(index, 2)
		destinationID = Worksheets("Master").Cells(index, 3)
		If entity > 0 Then
			If originID = 1 Then
				linkNum = 39
			ElseIf originID = 2 Then
				linkNum = 29
			ElseIf originID = 3 Then
				linkNum = 77
			ElseIf originID = 4 Then
				linkNum = 102
			ElseIf originID = 5 Then
				linkNum = 76
```

```
                Else
                      linkNum = 50
                End If
                If destinationID = 1 Then
                      vehType = 100
                ElseIf destinationID = 2 Then
                      vehType = 200
                ElseIf destinationID = 3 Then
                      vehType = 300
                ElseIf destinationID = 5 Then
                      vehType = 800
                Else
                      vehType = 500
                End If
                Set vehicle =
                vissim.net.Vehicles.AddVehicleAtLinkCoordinate(veh
                Type, 50, linkNum, 1, 0)
                Worksheets("VehID").Cells(index, 1) = vehicle.ID
                Worksheets("VehID").Cells(index, 2) = fTime
                index = index + 1
          End If
    Loop
Next

End Sub
```

APPENDIX-B

Table 29: Master Database Worksheet

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
1	3	4	1	1	2
2	317	4	1	10	11
3	354	4	1	19	20
4	391	4	1	28	29
5	428	4	1	37	38
6	465	4	1	46	47
7	502	4	3	55	56
8	539	4	2	64	65
9	576	4	3	73	74
10	613	4	3	82	83
11	650	4	1	91	92
12	687	4	3	100	101
13	724	4	3	109	110
14	761	4	1	118	119
15	798	4	1	127	128
16	835	4	2	136	137
17	872	4	1	145	146
18	909	4	1	154	155
19	946	4	1	163	164
20	983	4	3	172	173
21	1020	4	3	181	182
22	1057	4	3	190	191
23	1094	4	3	199	200
24	1131	4	3	208	209
25	1168	4	2	217	218
26	1205	4	2	226	227
27	1242	4	1	235	236
28	1279	4	1	244	245
29	1316	4	1	253	254
30	1353	4	1	262	263
31	1390	4	3	271	272
32	1427	4	1	280	281
33	1464	4	2	289	290
34	1501	4	2	298	299
35	1538	4	1	307	308
36	1575	4	3	316	317
37	1612	4	3	325	326
38	1649	4	1	334	335
39	1686	4	3	343	344
40	1723	4	3	352	353

Table 24: (continued)

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
41	1760	4	2	361	362
42	1797	4	1	370	371
43	1834	4	1	379	380
44	1871	4	1	388	389
45	1908	4	1	397	398
46	1945	4	3	406	407
47	1982	4	3	415	416
48	2019	4	1	424	425
49	2056	4	2	433	434
50	2093	4	3	442	443
51	2130	4	1	451	452
52	2167	4	1	460	461
53	2204	4	2	469	470
54	2241	4	3	478	479
55	2278	4	2	487	488
56	2315	4	1	496	497
57	2352	4	2	505	506
58	2389	4	3	514	515
59	2426	4	1	523	524
60	2463	4	1	532	533
61	3	1	4	480	540
62	2500	4	1	541	542
63	2533	4	1	550	551
64	502	3	4	525	554
65	2574	4	1	559	560
66	2611	4	3	568	569
67	317	1	4	513	576
68	2648	4	1	577	578
69	354	1	4	523	586
70	2685	4	1	586	587
71	539	2	4	567	590
72	391	1	4	533	593
73	2722	4	1	595	596
74	428	1	4	538	597
75	465	1	4	545	600
76	576	3	4	567	600
77	2759	4	1	604	605
78	613	3	4	572	606
79	2796	4	2	613	614
80	687	3	4	580	621
81	2833	4	1	622	623

Table 24: (continued)

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
82	724	3	4	590	627
83	2870	4	3	631	632
84	2907	4	1	640	641
85	650	1	4	586	649
86	2944	4	1	649	650
87	835	2	4	633	653
88	2977	4	1	658	659
89	3018	4	1	667	668
90	3055	4	2	676	677
91	983	3	4	649	680
92	3092	4	1	685	686
93	761	1	4	633	688
94	798	1	4	637	694
95	3129	4	3	694	695
96	3166	4	1	703	704
97	872	1	4	646	707
98	3203	4	1	712	713
99	909	1	4	650	713
100	1057	3	4	687	714
101	1020	3	4	683	718
102	946	1	4	661	720
103	1168	2	4	703	721
104	3240	4	1	721	722
105	1094	3	4	697	729
106	1205	2	4	706	730
107	3277	4	3	730	731
108	1131	3	4	701	737
109	3314	4	3	739	740
110	3351	4	1	748	749
111	3388	4	3	757	758
112	3425	4	2	766	767
113	1242	1	4	715	775
114	3462	4	3	775	776
115	1464	2	4	765	782
116	3499	4	1	784	785
117	1501	2	4	770	785
118	1390	3	4	752	790
119	3536	4	1	793	794
120	3573	4	1	802	803
121	3610	4	3	811	812
122	1279	1	4	753	817

Table 24: (continued)

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
123	1316	1	4	759	820
124	3647	4	3	820	821
125	1353	1	4	765	825
126	3684	4	1	829	830
127	1427	1	4	772	832
128	1575	3	4	805	836
129	1612	3	4	809	836
130	3721	4	1	838	839
131	1686	3	4	820	845
132	3758	4	3	847	848
133	3795	4	3	856	857
134	1723	3	4	825	861
135	3832	4	3	865	866
136	1538	1	4	813	871
137	3869	4	1	874	875
138	3906	4	1	883	884
139	1649	1	4	824	884
140	3943	4	1	892	893
141	1760	2	4	867	895
142	1945	3	4	882	913
143	1982	3	4	890	926
144	1797	1	4	878	940
145	1834	1	4	882	942
146	2056	2	4	931	950
147	1871	1	4	890	955
148	2204	2	4	944	957
149	1908	1	4	898	961
150	2093	3	4	929	962
151	2241	3	4	949	978
152	2019	1	4	933	992
153	2130	1	4	941	996
154	2278	2	4	987	1006
155	2167	1	4	951	1010
156	2352	2	4	991	1011
157	2389	3	4	993	1029
158	2315	1	4	995	1058
159	2426	1	4	1008	1069
160	2463	1	4	1015	1076
161	2611	3	4	1050	1085
162	2500	1	4	1052	1112
163	2533	1	4	1060	1118

Table 24: (continued)

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
164	2574	1	4	1067	1128
165	2648	1	4	1071	1128
166	2796	2	4	1110	1130
167	2870	3	4	1114	1136
168	2722	1	4	1082	1138
169	2685	1	4	1078	1140
170	2759	1	4	1113	1175
171	2833	1	4	1124	1189
172	2907	1	4	1134	1194
173	2944	1	4	1138	1197
174	3055	2	4	1174	1198
175	3129	3	4	1177	1209
176	2977	1	4	1173	1233
177	3018	1	4	1180	1241
178	3092	1	4	1186	1249
179	3166	1	4	1193	1251
180	3425	2	4	1241	1258
181	3203	1	4	1201	1260
182	3277	3	4	1226	1261
183	3314	3	4	1229	1265
184	3388	3	4	1239	1268
185	3462	3	4	1249	1282
186	3240	1	4	1236	1297
187	3351	1	4	1246	1305
188	3610	3	4	1296	1319
189	3647	3	4	1303	1335
190	3499	1	4	1296	1354
191	3536	1	4	1300	1361
192	3573	1	4	1306	1369
193	3684	1	4	1318	1379
194	3795	3	4	1351	1384
195	3758	3	4	1347	1385
196	3832	3	4	1361	1388
197	3721	1	4	1353	1413
198	3869	1	4	1364	1422
199	3906	1	4	1375	1434
200	3943	1	4	1383	1443

Table 30: Port of Savannah Database Worksheet

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
1	3	4	1	1	2
2	317	4	1	10	11
3	354	4	1	19	20
4	391	4	1	28	29
5	428	4	1	37	38
6	465	4	1	46	47
7	650	4	1	91	92
8	761	4	1	118	119
9	798	4	1	127	128
10	872	4	1	145	146
11	909	4	1	154	155
12	946	4	1	163	164
13	1242	4	1	235	236
14	1279	4	1	244	245
15	1316	4	1	253	254
16	1353	4	1	262	263
17	1427	4	1	280	281
18	1538	4	1	307	308
19	1649	4	1	334	335
20	1797	4	1	370	371
21	1834	4	1	379	380
22	1871	4	1	388	389
23	1908	4	1	397	398
24	2019	4	1	424	425
25	2130	4	1	451	452
26	2167	4	1	460	461
27	2315	4	1	496	497
28	2426	4	1	523	524
29	2463	4	1	532	533
30	2500	4	1	541	542
31	2533	4	1	550	551
32	2574	4	1	559	560
33	2648	4	1	577	578
34	2685	4	1	586	587
35	2722	4	1	595	596
36	2759	4	1	604	605
37	2833	4	1	622	623
38	2907	4	1	640	641
39	2944	4	1	649	650
40	2977	4	1	658	659

Table 25: (continued)

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
41	3018	4	1	667	668
42	3092	4	1	685	686
43	3166	4	1	703	704
44	3203	4	1	712	713
45	3240	4	1	721	722
46	3351	4	1	748	749
47	3499	4	1	784	785
48	3536	4	1	793	794
49	3573	4	1	802	803
50	3684	4	1	829	830
51	3721	4	1	838	839
52	3869	4	1	874	875
53	3906	4	1	883	884
54	3943	4	1	892	893

Table 31: Distribution Center 1 Database Worksheet

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
1	539	4	2	64	65
2	835	4	2	136	137
3	1168	4	2	217	218
4	1205	4	2	226	227
5	1464	4	2	289	290
6	1501	4	2	298	299
7	1760	4	2	361	362
8	2056	4	2	433	434
9	2204	4	2	469	470
10	2278	4	2	487	488
11	2352	4	2	505	506
12	2796	4	2	613	614
13	3055	4	2	676	677
14	3425	4	2	766	767

Table 32: Distribution Center 2 Database Worksheet

RN	Container ID	Origin ID	Destination ID	Time In	Time Out
1	502	4	3	55	56
2	576	4	3	73	74
3	613	4	3	82	83
4	687	4	3	100	101
5	724	4	3	109	110
6	983	4	3	172	173
7	1020	4	3	181	182
8	1057	4	3	190	191
9	1094	4	3	199	200
10	1131	4	3	208	209
11	1390	4	3	271	272
12	1575	4	3	316	317
13	1612	4	3	325	326
14	1686	4	3	343	344
15	1723	4	3	352	353
16	1945	4	3	406	407
17	1982	4	3	415	416
18	2093	4	3	442	443
19	2241	4	3	478	479
20	2389	4	3	514	515
21	2611	4	3	568	569
22	2870	4	3	631	632
23	3129	4	3	694	695
24	3277	4	3	730	731
25	3314	4	3	739	740
26	3388	4	3	757	758
27	3462	4	3	775	776
28	3610	4	3	811	812
29	3647	4	3	820	821
30	3758	4	3	847	848
31	3795	4	3	856	857
32	3832	4	3	865	866

Table 33: Vehicle ID Database Worksheet

RN	Vehicle ID	Time In	Time Out
1	1	2	480
2	2	11	513
3	3	20	523
4	4	29	533
5	5	38	538
6	6	47	545
7	7	56	525
8	8	65	567
9	9	74	567
10	10	83	572
11	11	92	586
12	12	101	580
13	13	110	590
14	14	119	633
15	15	128	637
16	16	137	633
17	17	146	646
18	18	155	650
19	19	164	661
20	20	173	649
21	21	182	683
22	22	191	687
23	23	200	697
24	24	209	701
25	25	218	703
26	26	227	706
27	27	236	715
28	28	245	753
29	29	254	759
30	30	263	765
31	31	272	752
32	32	281	772
33	33	290	765
34	34	299	770
35	35	308	813
36	36	317	805
37	37	326	809
38	38	335	824
39	39	344	820
40	40	353	825

Table 28: (continued)

RN	Vehicle ID	Time In	Time Out
41	41	362	867
42	42	371	878
43	43	380	882
44	44	389	890
45	45	398	898
46	46	407	882
47	47	416	890
48	48	425	933
49	49	434	931
50	50	443	929
51	51	452	941
52	52	461	951
53	53	470	944
54	54	479	949
55	55	488	987
56	56	497	995
57	57	506	991
58	58	515	993
59	59	524	1008
60	60	533	1015
61	61	540	1016
62	62	542	1052
63	63	551	1060
64	64	554	1023
65	65	560	1067
66	66	569	1050
67	67	576	1076
68	68	578	1071
69	69	586	1093
70	70	587	1078
71	71	590	1062
72	72	593	1099
73	73	596	1082
74	74	597	1115
75	75	600	1119
76	76	600	1085
77	77	605	1113
78	78	606	1108
79	79	614	1110
80	80	621	1112
81	81	623	1124

Table 28: (continued)

RN	Vehicle ID	Time In	Time Out
82	82	627	1123
83	83	632	1114
84	84	641	1134
85	85	649	1136
86	86	650	1138
87	87	653	1127
88	88	659	1173
89	89	668	1180
90	90	677	1174
91	91	680	1150
92	92	686	1186
93	93	688	1196
94	94	694	1211
95	95	695	1177
96	96	704	1193
97	97	707	1224
98	98	713	1201
99	99	713	1232
100	100	714	1201
101	101	718	1217
102	102	720	1237
103	103	721	1192
104	104	722	1236
105	105	729	1228
106	106	730	1244
107	107	731	1226
108	108	737	1241
109	109	740	1229
110	110	749	1246
111	111	758	1239
112	112	767	1241
113	113	775	1261
114	114	776	1249
115	115	782	1254
116	116	785	1296
117	117	785	1289
118	118	790	1267
119	119	794	1300
120	120	803	1306
121	121	812	1296
122	122	817	1316

Table 28: (continued)

RN	Vehicle ID	Time In	Time Out
123	123	820	1325
124	124	821	1303
125	125	825	1334
126	126	830	1318
127	127	832	1356
128	128	836	1319
129	129	836	1344
130	130	839	1353
131	131	845	1350
132	132	848	1347
133	133	857	1351
134	134	861	1362
135	135	866	1361
136	136	871	1378
137	137	875	1364
138	138	884	1375
139	139	884	1386
140	140	893	1383
141	141	895	1369
142	142	913	1393
143	143	926	1400
144	144	940	1436
145	145	942	1453
146	146	950	1421
147	147	955	1457
148	148	957	1428
149	149	961	1469
150	150	962	1445
151	151	978	1462
152	152	992	1496
153	153	996	1515
154	154	1006	1477
155	155	1010	1520
156	156	1011	1482
157	157	1029	1505
158	158	1058	1556
159	159	1069	1569
160	160	1076	1575
161	161	1085	1563
162	162	1112	1616
163	163	1118	1630

Table 28: (continued)

RN	Vehicle ID	Time In	Time Out
164	164	1128	1634
165	165	1128	1638
166	166	1130	1601
167	167	1136	1623
168	168	1138	1642
169	169	1140	1646
170	170	1175	1677
171	171	1189	1693
172	172	1194	1698
173	173	1197	1703
174	174	1198	1669
175	175	1209	1686
176	176	1233	1736
177	177	1241	1749
178	178	1249	1753
179	179	1251	1758
180	180	1258	1730
181	181	1260	1783
182	182	1261	1743
183	183	1265	1762
184	184	1268	1772
185	185	1282	1777
186	186	1297	1796
187	187	1305	1814
188	188	1319	1804
189	189	1335	1820
190	190	1354	1856
191	191	1361	1867
192	192	1369	1879
193	193	1379	1887
194	194	1384	1860
195	195	1385	1874
196	196	1388	1892
197	197	1413	1916
198	198	1422	1924
199	199	1434	1930
200	200	1443	1935

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